BgNS TRANSACTIONS volume **22** number 1 (2017) pp. 46–49

# Indoor Radon Measurements in Plovdiv City

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**Abstract.** Radon is a radioactive gas that is formed naturally by the breakdown of uranium in soil, rock and water. Recent epidemiological findings from residential studies demonstrate a statistically significant increase of lung cancer risk from prolonged exposure to indoor radon. The new requirements of ICRP and WHO include the control of indoor exposure due radon and establishment of a reference level for the annual average activity concentration up to 300 Bq/m$^3$ for existing dwellings and public buildings.

In this paper the results of indoor radon survey in Plovdiv city are presented. Radon measurements were made in 44 dwellings and 91 kindergartens by using CR-39 nuclear track detectors. The detectors in dwellings were exposed for 6 months from October 2011 to May 2012 while the detectors in kindergartens for 3 month from January to April 2014. The average annual indoor radon concentration (GM) for dwelling was found to be 100 Bq/m$^3$ and for kindergartens 230 Bq/m$^3$. The maximum measurement value of radon concentration in dwellings was 930 Bq/m$^3$ and for kindergartens 1094 Bq/m$^3$. The radon concentrations in dwellings were compared with that in kindergartens and the results show that kindergartens have a high indoor radon concentration than dwellings. A detailed statistical analysis of the building factors was presented as well as the risk from radon exposure was assessed.

**Keywords:** indoor radon, passive detectors, dwellings, kindergartens.

## 1 Introduction

Radon is a naturally occurring radioactive gas which originates from the decay of uranium present in rocks and soils. When radon surfaces in the open air, it is quickly diluted to harmless concentrations, but when it enters an enclosed space, such as a house or any other building, it can sometimes accumulate to relatively high concentrations. Indoor radon concentrations can vary significantly due to a large number of factors which include the local geology, soil permeability, building and lifestyle characteristics and climate [1].

Exposure to indoor radon and its decay products contributes half of the annual dose received by the public from all sources [2]. The long-term effect of radon exposure lung cancer is widely recognised [3]. Many epidemiological case–control studies have been carried out to estimate the risk of lung cancer due to residential radon exposure [4,5]. The new requirements of ICRP and WHO include the control of indoor exposure due radon and establishment of a reference level for the annual average activity concentration up to 300 Bq/m$^3$ for existing dwellings and public buildings. To meet these requirements, many countries have carried out research not only in dwellings but in schools and kindergartens. Same of those are Ireland [6], Slovenia [7], in the Neapolitan area of Italy [8], Serbia [9,10], etc. Kindergartens are more complicated buildings than residences. Little children spend all day in kindergartens and so they have a space for games, bedrooms, dining rooms, gyms and kitchens. For that reason the investigation of kindergarten buildings is important to provide a check on the quality of the air that children breathe.

In order to obtained first systematic data, a pilot survey of indoor radon concentration has been conducted in four regions of Bulgaria (Plovdiv, Burgas, Sofia-city, Sofia-district) under the Regional Project of the International Atomic Energy Agency [11].

This paper presents the results of systematic indoor radon measurements in public kindergartens in Plovdiv city performed from January to April 2014. The radon concentrations obtained in this survey are compared with those gained under the pilot survey.

## 2 Materials and Methods

Radon measurements were made in 91 kindergartens. The survey was carried out in all public kindergartens according to the information system of Plovdiv city from January to April 2014. The first step in this survey was collecting the information about the number of rooms on ground floor by telephone. The second one was to prepare a package with the detectors, instruction forms, brochures and questionnaires. Kindergarten managers were gathered by Plovdiv city mayoralty to inform them about radon (to minimize misinformation and anxiety), to instruct them about deploying detectors and to distributed the packages. Thus, the detectors were distributed within a day. Seven per cent of the measured kindergartens were visited for on-site inspection of detectors set and distribution of duplicate detectors for quality control purpose. All the detectors were collected after 3 months by kindergarten staffs who return them to the laboratory. The losses of detectors and uncorrected measurements were 5%. Analysis and processing of the results were performed in the labo-

ratory 'Radon Monitoring and Prevention' at the National Centre of Radiobiology and Radiation Protection following the international standard [12].

The commercially named RSKS nuclear track detector, used in this survey, consisted of a CR-39 chip placed on the bottom of the cylindrical diffusion chamber. After collection of the detectors, the CR-39 chips were detached from the diffusion chamber and were chemically etched in 6.25-M solution of NaOH at a temperature of 90°C for 3.4 h (these parameters are recommended by the manufacturer).

The results of the survey in dwellings in Plovdiv were conducted from October 2011 to May 2012. The results are published in Journal of Radiation Protection Dosimetry [11]. Radon measurements were made in 44 dwellings. The measurements were performed using the commercially available nuclear track detectors that are widely used for long-term measurements of indoor radon concentration. The detector consists of a CR-39 chip with active area of 1.4 $cm^2$ placed in a cylindrical diffusion chamber. The detectors were exposed for 6 months. They were placed at least 1 m above the floor and at least 10 cm from any objects.

All the data were compiled into Microsoft Excel spread sheets, and the statistical analysis was performed with the IBM SPSS Statistics statistical software.

## 3 Results and Discussion

Summary statistics of indoor radon measurements in kindergartens are presented in Table 1. The geometric means (GM) of radon measurements in kindergartens is 230 $Bq.m^{-3}$ and is higher than in kindergartens in Sofia city 101 $Bq.m^{-3}$ [13]. This can be explained by the different geology of the regions. The maximum measured value is 1094 $Bq.m^{-3}$ and 44% of the buildings of kindergartens have values higher than the reference level of 300 $Bq.m^{-3}$ for the public building, according to the Bulgarian national legislation. In order to determine distribution of the data, the values of the measured results were compared with a log-normal distribution; Shapiro-Wilk test was used at the 95 % significance level ($p < 0.05$, the test is significant). The null hypothesis that overall data have a log-normal distribution was rejected (SW, $p=0.006$). The results are present on the Normal Q-Q plot on Figure 1. These results indicate that the Plovdiv region is likely to be radon prone area.

The GM of 230 $Bq/m^3$ in this study was higher than those of 100 $Bq/m^3$ obtained in the survey of dwellings in

Table 1. Descriptive statistics

| | Radon concentration [$Bq/m^3$] | |
|---|---|---|
| | kindergarten | dwelling |
| Number | 91 | 44 |
| ***AM*** | ***278*** | ***135*** |
| Median | 275 | 90 |
| SDV | 160 | 177 |
| Range | 641 | 890 |
| Minimum | 54 | 40 |
| Maximum | 1094 | 930 |
| ***GM*** | ***230*** | ***100*** |

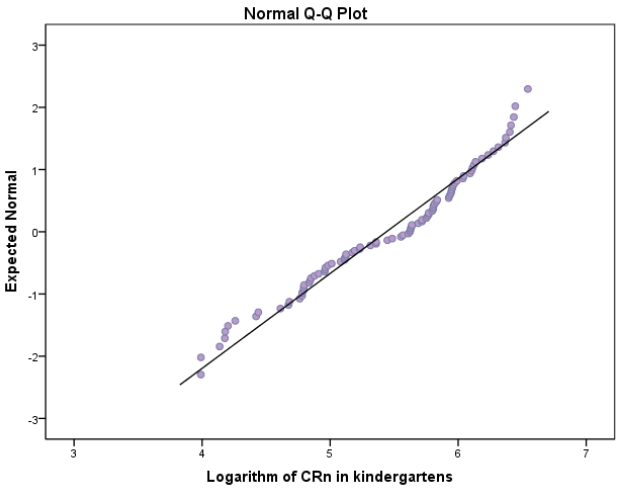


Figure 1. Distribution of annual radon concentration on the Q-Q plot.

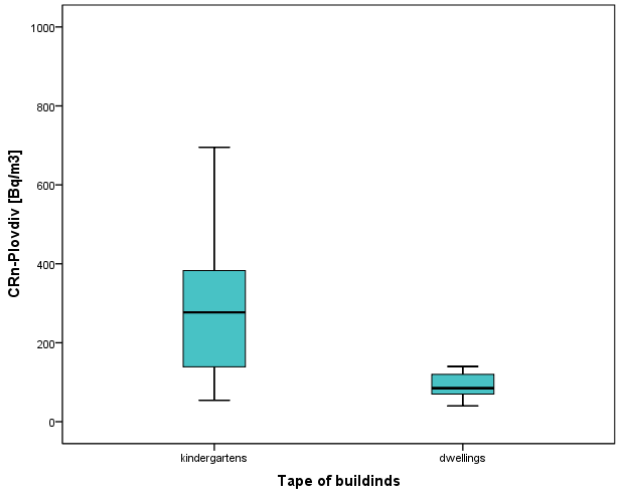


Figure 2. Box plot of indoor radon concentration in kindergartens and dwellings.

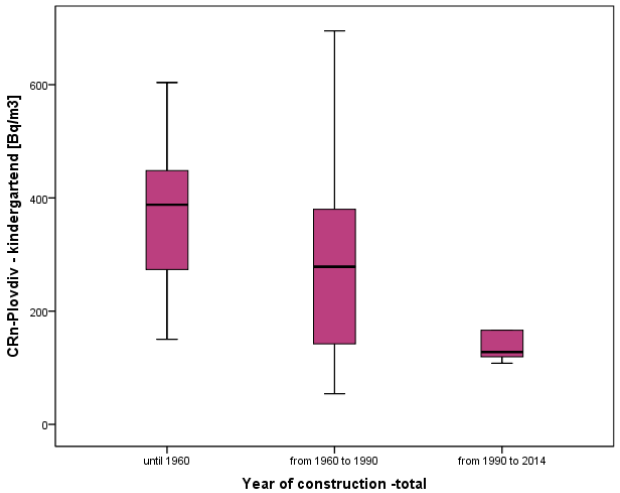


Figure 3. Box plot of indoor radon concentration in kindergartens accourding the year of constuction.

Plovdiv city. Box plot of indoor radon concentration in kindergartens and dwellings is present on the Figure 2. For comparison of the results the independent Student's t-test were applied. Correctness of equality between the two

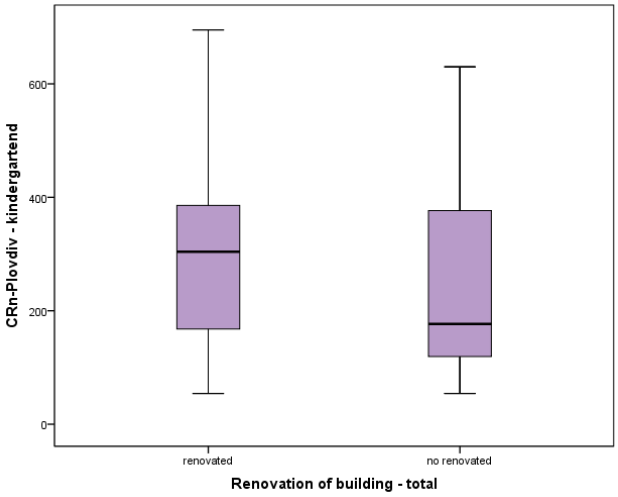


Figure 4. Box plot of indoor radon concentration in renovated and not renovated buildings.

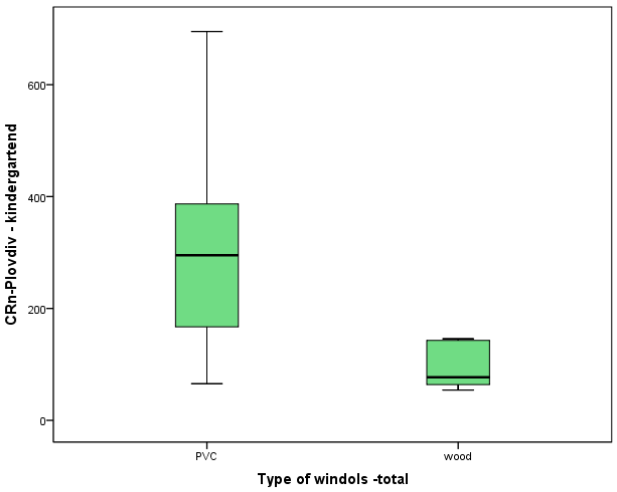


Figure 5. Box plot of indoor radon concentration in buildings with PVC type of windows and wood.

samples of measurements is checked according to the indicator "Significance (2-tailed)" ($p > 0.05$), as previously the results are tested for the equality between variations with Levin's test (LT). It is assumed that the variances are equal when the Levin's test is $p > 0.05$. The variances of radon concentration in dwelling and kindergartens in Plovdiv city are assumed to be not equal (LT, $p = 0.032$. According to the applied Student test (t, $p < 0.001$) there is statistically significant difference between the measured indoor radon concentrations in kindergartens and dwellings. This can be explained by the building construction and occupation features, as well as varying season when measurements were performed.

In order to investigate different factors that affect the indoor radon concentration, further statistical analyses were performed. To assess the influence of year of construction on indoor radon concentration, the results in kindergartens are split in 3 groups and ANOVA test was applied. There is significant difference between groups when the $p < 0.05$ at 95% confidence level measured in each groups of results. The first group is kindergartens which were built until 1960; the second is the results of buildings constructed from 1960 to 1990 and third group from 1990 to 2014. The box-plot of radon concentration in different group of kindergartens, divided according the years of construction (Figure 3). Test for homogeneity of variance between the groups is showed that variance in scores is the same for each of three groups (LT, $p = 0.752$). There is no statistical significant difference between indoor radon level between the three groups (ANOVA, $p = 0.071$). One of the main reasons for the lack of statistical significant difference between the values of the indoor radon concentration according the year of construction is that the old buildings have begun to be renovated, as well as changing the type of windows. To investigate this influence the independent Student's t-test were applied.

The box plot of indoor radon concentration in renovated and not renivated buildings were presented in Figure 4. Variances in the indoor radon concentration in renovated and not renovated building is assumed to be equal (LT, $p = 0.240$). The Student's t-test shows no significant differences between indoor radon concentrations measured in renovated and no renovated buildings (t, $p = 0.196$). Whereas between radon concentrations measured in buildings with a new type (PVC) of windows and old type (wood) there are statistically significant difference (t, $p$ =*0.001*). Test for homogeneity of variance between radon concentration in building with PVC and buildings with wood type of windows is showed that variance is the same for each groups (LT, $p = 0.160$). The results of radon concentration in kindergartens according the type of windows are presented on the box-plot (Figure 5). This indicates that the reconstruction of the building does not affect so much on the concentration of radon than the change in the ventilation of the building. When replacing old windows with new type, ventilation of the building is reduced at the expense of saving energy.

## 4 Conclusion

The results of systematic measurement in kindergartens in Plovdiv city indicate that the Plovdiv region is likely to be radon prone area. More than 40% of all state kindergartens have radon concentrations over than the reference level of 300 Bq/m$^3$ for the public building, according to the Bulgarian national legislation. The geometric means (GM) of radon measurements in kindergartens is 230 Bq/m$^3$ and is higher than in kindergartens in Sofia city 101 Bq/m$^3$.

Statistically significant difference between the measured indoor radon concentrations in kindergartens and dwellings is obtained, which show the difference in building construction and occupation features. The buildings of kindergartens have higher levels of radon concentration in comparison with the dwelling. Children spend much of their time in kindergartens for that these buildings should also be investigated. The distribution of detectors trough majority is easy and quick way.

Renovations of the building and change the old windows with new one (PVC, ect.) without taking into account the radon, may increase the indoor radon concentration in the building. There are easy and expensive ways for reducing the indoor radon concentration, for this when the build-

ings is going to be renovated it should be take into account the concentration of radon in order to improve air quality in kindergartens.

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